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Inoue et al.

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(54) **ACTIVE SOUND EFFECT GENERATING APPARATUS**

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G10K 15/02 (2006.01)
B60Q 5/00 (2006.01)

(52) **U.S. Cl.**

CPC ***G10K 15/02*** (2013.01); ***B60Q 5/00*** (2013.01); *Y10S 903/902* (2013.01)

(58) **Field of Classification Search**

CPC B60Q 5/00

USPC 381/61

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,848,168 A * 12/1998 Shipps F01N 1/065 381/71.5
8,045,723 B2 10/2011 Kobayashi et al.
2004/0240677 A1* 12/2004 Onishi G10K 11/1784 381/71.4
2004/0247137 A1 12/2004 Inoue et al.
2006/0215846 A1 9/2006 Kobayashi et al.
2008/0313642 A1* 12/2008 Karaoguz G06F 9/5027 718/104
2009/0028353 A1 1/2009 Kobayashi et al.
2012/0101611 A1* 4/2012 Inoue G10K 15/02 700/94
2013/0216054 A1 8/2013 Inoue

FOREIGN PATENT DOCUMENTS

JP 2004-361721 A 12/2004
JP 2006-301598 A 11/2006
JP 2009-31428 A 2/2009
JP 2012-131315 A 7/2012
JP 2013-167851 A 8/2013

* cited by examiner

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(57) **ABSTRACT**

A control signal generating unit in an active sound effect generating apparatus adjusts the amplitude of a control signal by varying the amplitudes of reference signals in accordance with an amount of change in frequency and a load of a driving source.

18 Claims, 7 Drawing Sheets

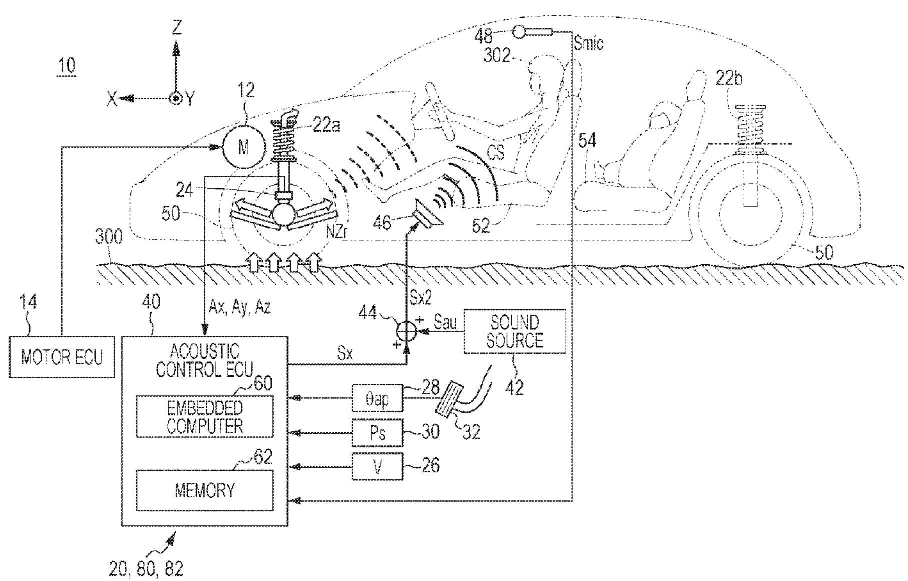
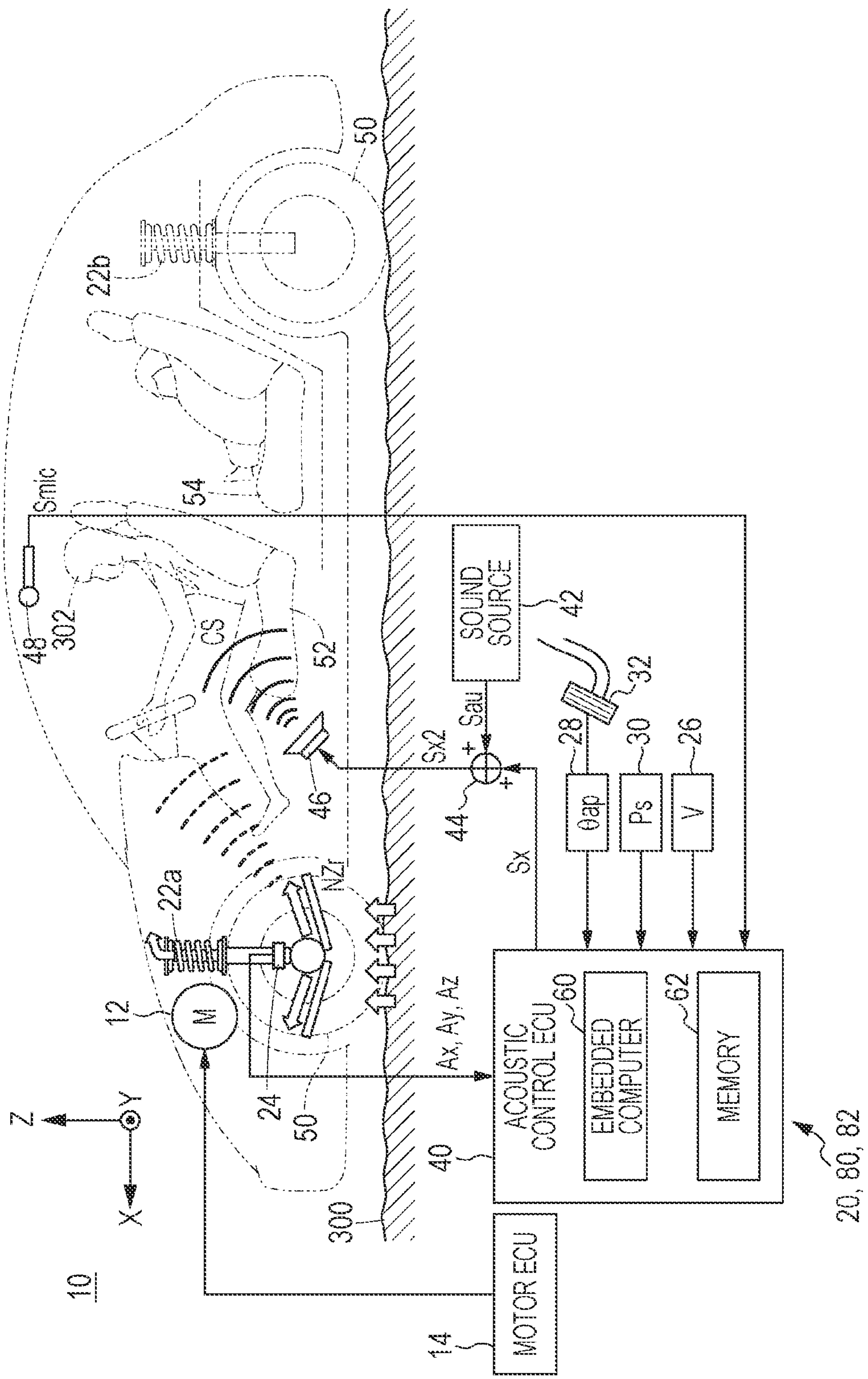


FIG. 1



10
Z
Y
X
12
M
22a
22b
24
50
NZr
Ax, Ay, Az
46
44
Sx
Sx2
Sau
CS
52
302
48
Smic
54
300
SOUND SOURCE
42
32
28
30
26
θap
Ps
V
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40
60
EMBEDDED COMPUTER
62
MEMORY
20, 80, 82
MOTOR ECU
14

FIG. 2

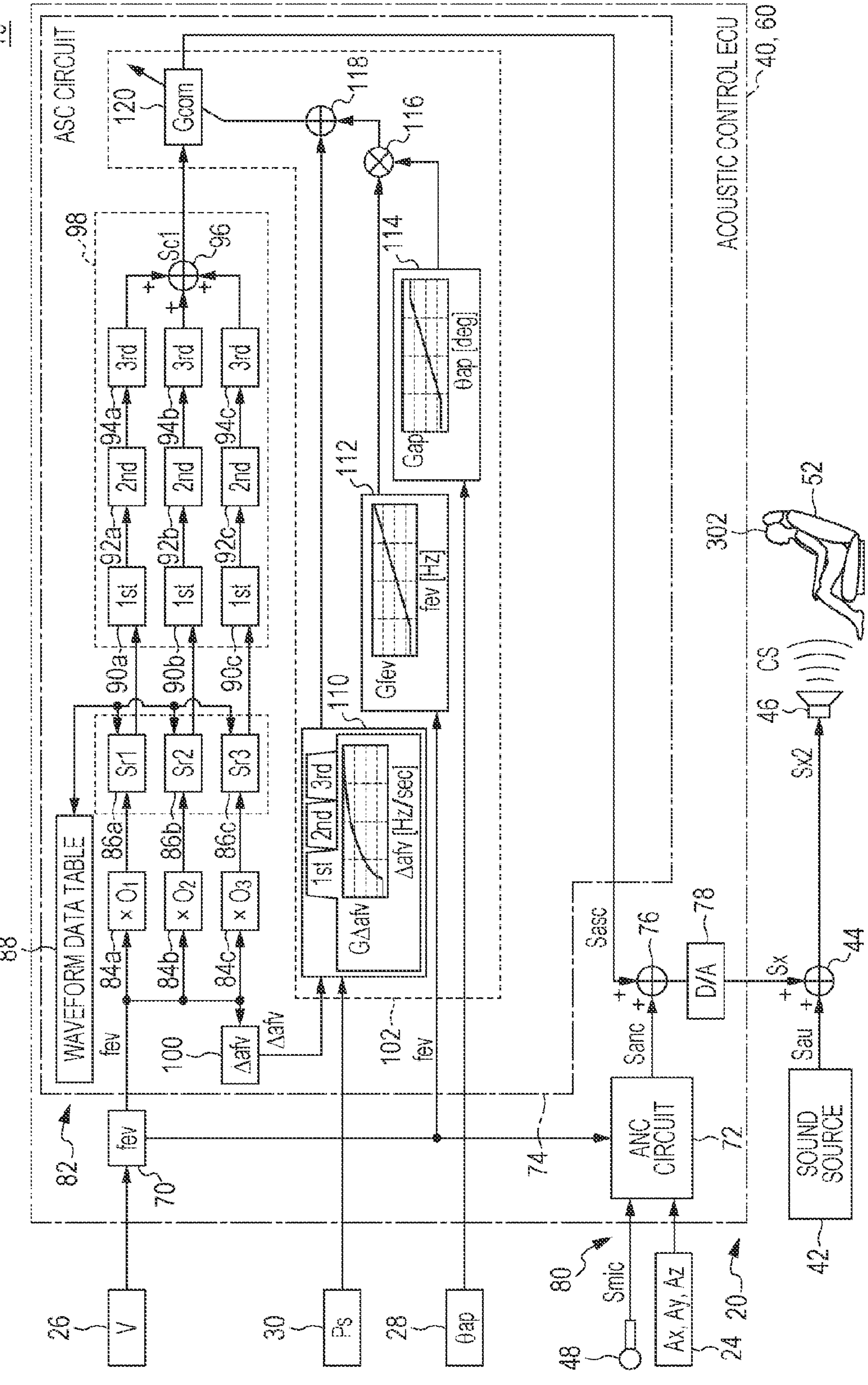
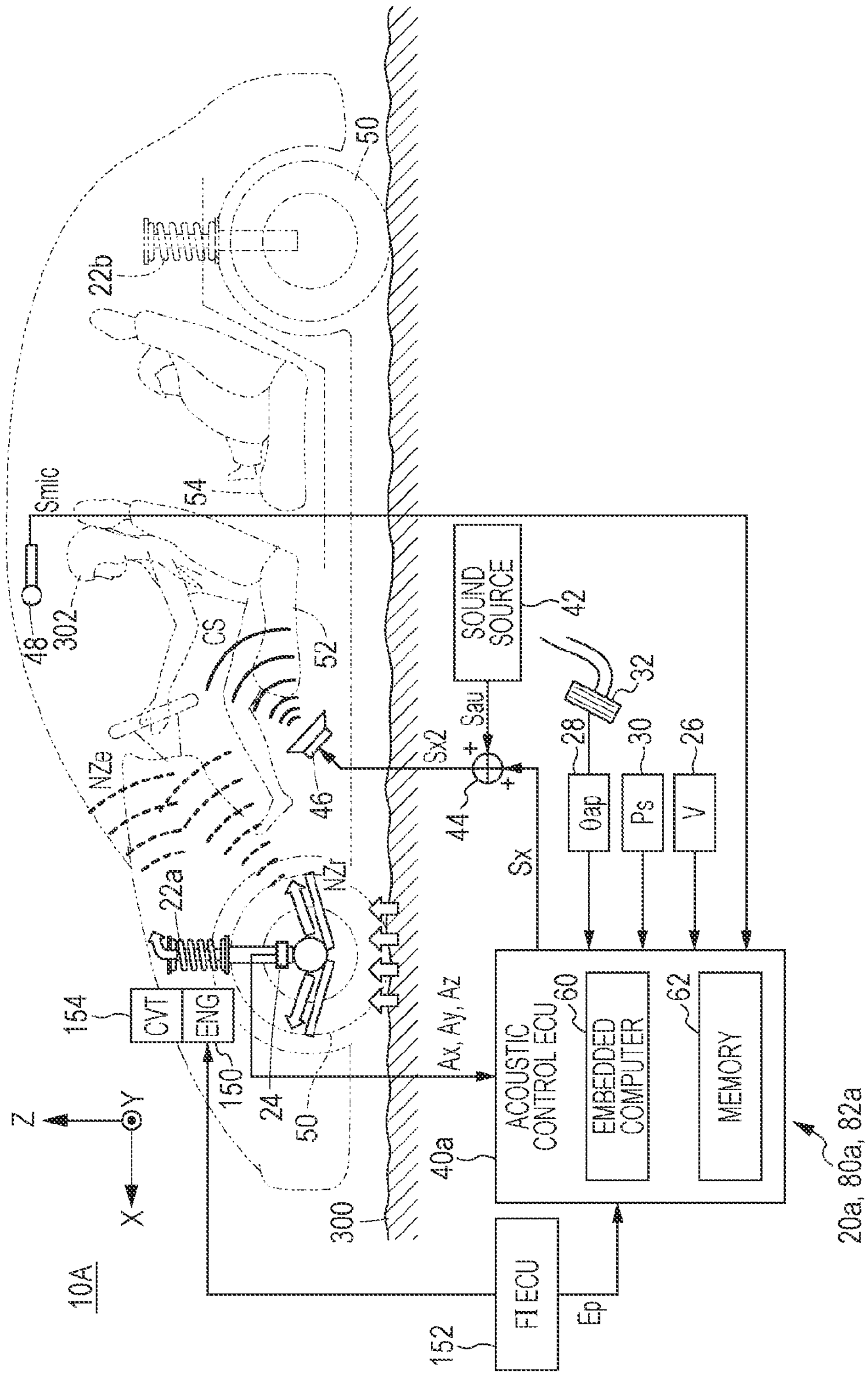

10
ASC CIRCUIT
ACOUSTIC CONTROL ECU
40, 60
WAVEFORM DATA TABLE
88
fev
Δafv
× O1
× O2
× O3
Sr1
Sr2
Sr3
1st
2nd
3rd
Sc1
Gcom
GΔafv
Δafv [Hz/sec]
Gfev
fev [Hz]
Gap
θap [deg]
Sasc
Sanc
Sx
Sx2
Sau
D/A
ANC CIRCUIT
SOUND SOURCE
CS
V
Ps
θap
Smic
Ax, Ay, Az

FIG. 3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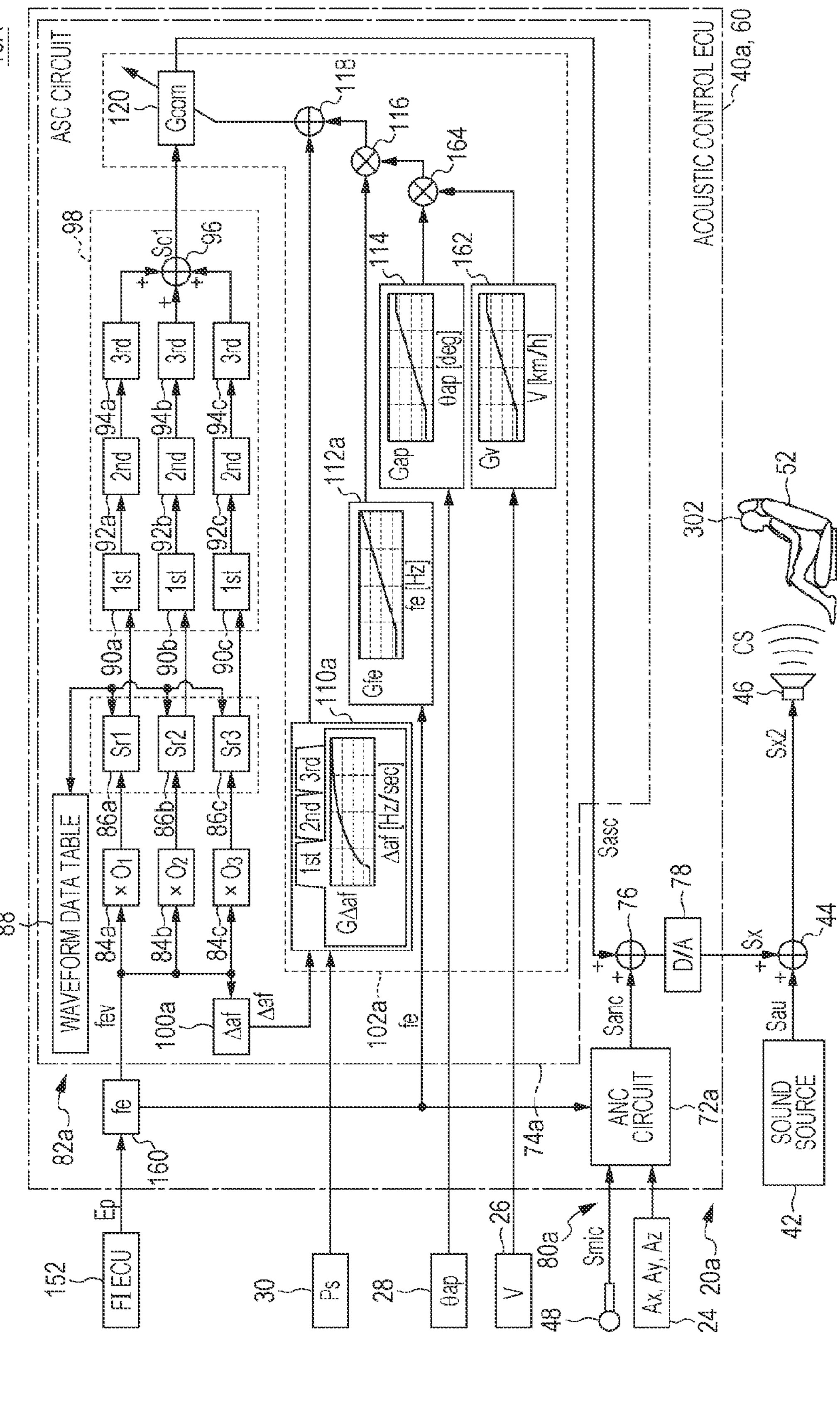
Y
X
300
50
24
150
154
CVT
ENG
22a
NZr
NZe
46
44
Sx
Sx2
Sau
52
CS
302
48
Smic
54
22b
SOUND SOURCE
42
32
28
30
26
θap
Ps
V
Ax, Ay, Az
ACOUSTIC CONTROL ECU
40a
60
EMBEDDED COMPUTER
62
MEMORY
20a, 80a, 82a
FI ECU
152
Ep

FIG. 4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ASC CIRCUIT
ACOUSTIC CONTROL ECU
40a, 60
WAVEFORM DATA TABLE
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fev
Δaf
100a
102a
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Sr1
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Sr3
1st
2nd
3rd
Sc1
96
98
Gcom
120
118
116
164
114
162
Gap
θap [deg]
Gv
V [km/h]
Gfe
fe [Hz]
112a
110a
GΔaf
Δaf [Hz/sec]
ANC CIRCUIT
72a
74a
82a
160
Sanc
Sasc
76
D/A
78
Sx
44
Sx2
46
CS
52
302
SOUND SOURCE
42
Sau
FI ECU
152
Ep
Ps
30
θap
28
V
26
Smic
80a
48
Ax, Ay, Az
24
20a

FIG. 5

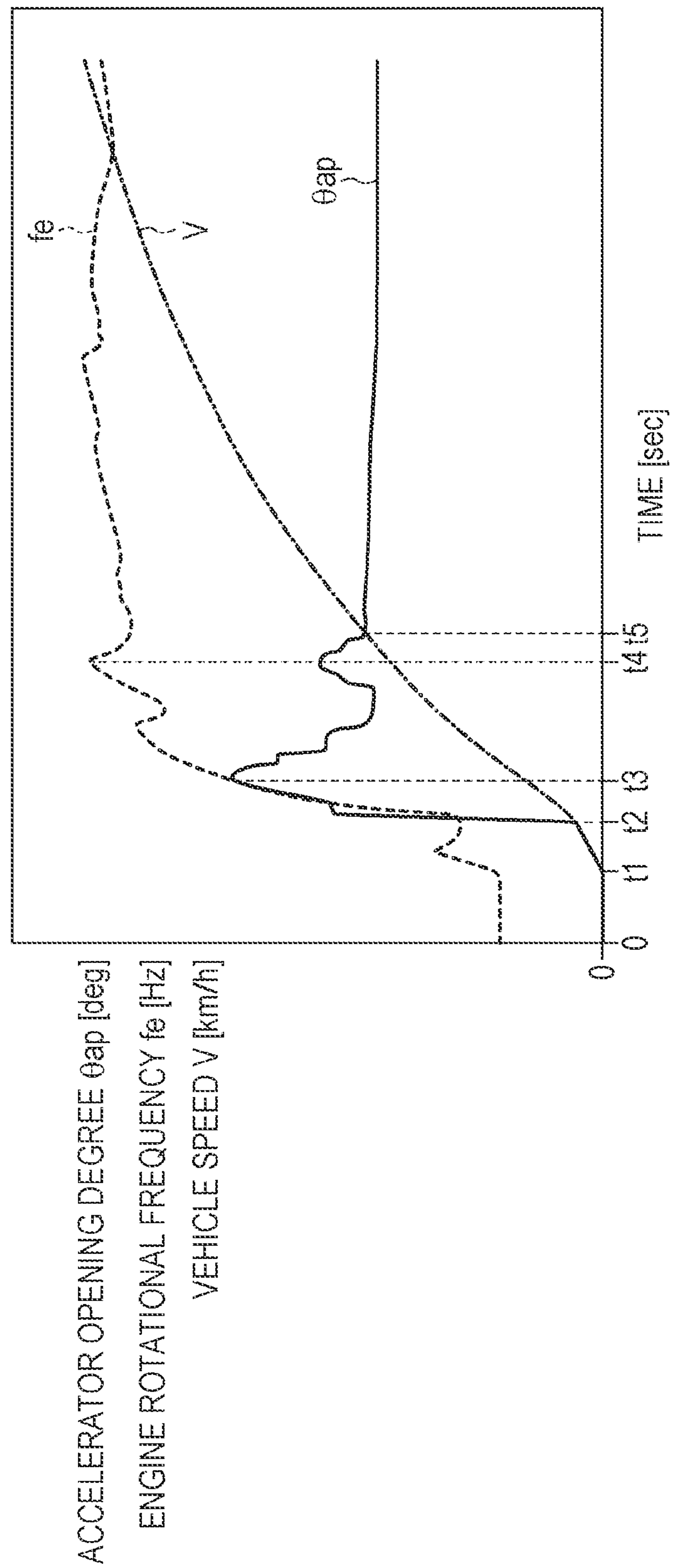

ACCELERATOR OPENING DEGREE θap [deg]
ENGINE ROTATIONAL FREQUENCY fe [Hz]
VEHICLE SPEED V [km/h]
TIME [sec]
0
0
t1
t2
t3
t4
t5
fe
V
θap

FIG. 6

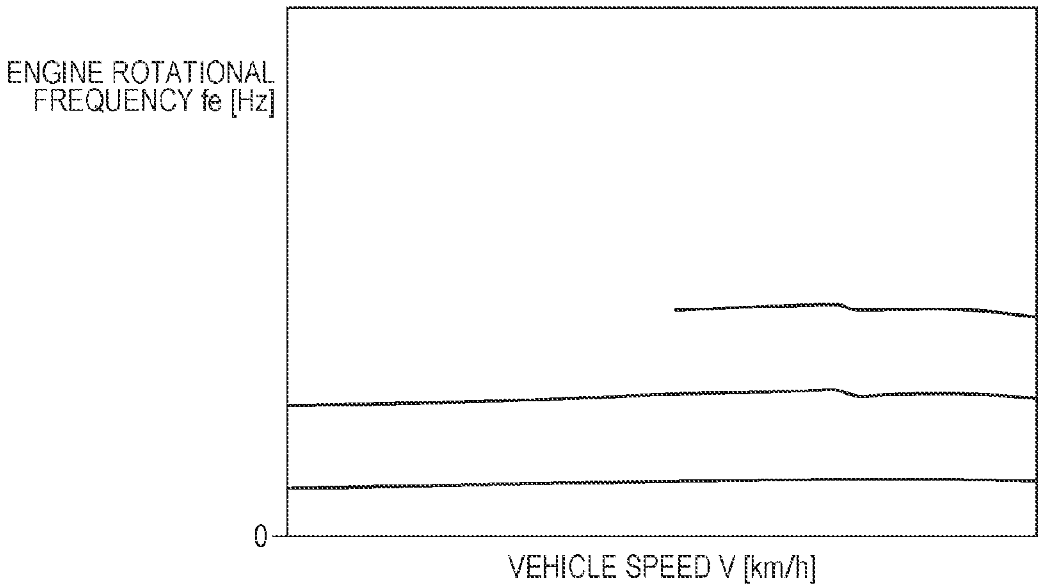

ENGINE ROTATIONAL FREQUENCY fe [Hz]
0
VEHICLE SPEED V [km/h]

FIG. 7

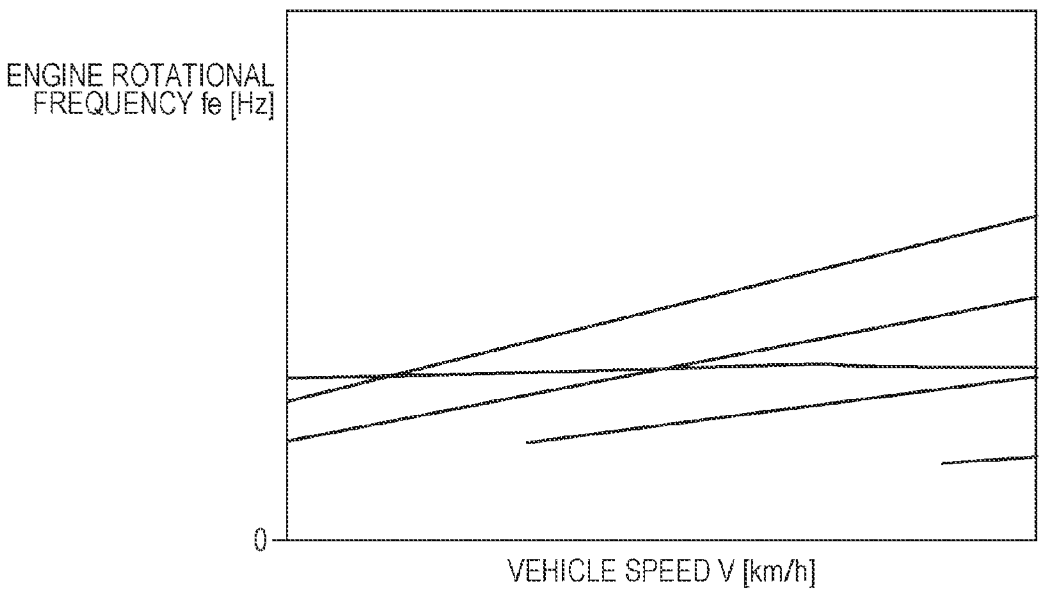
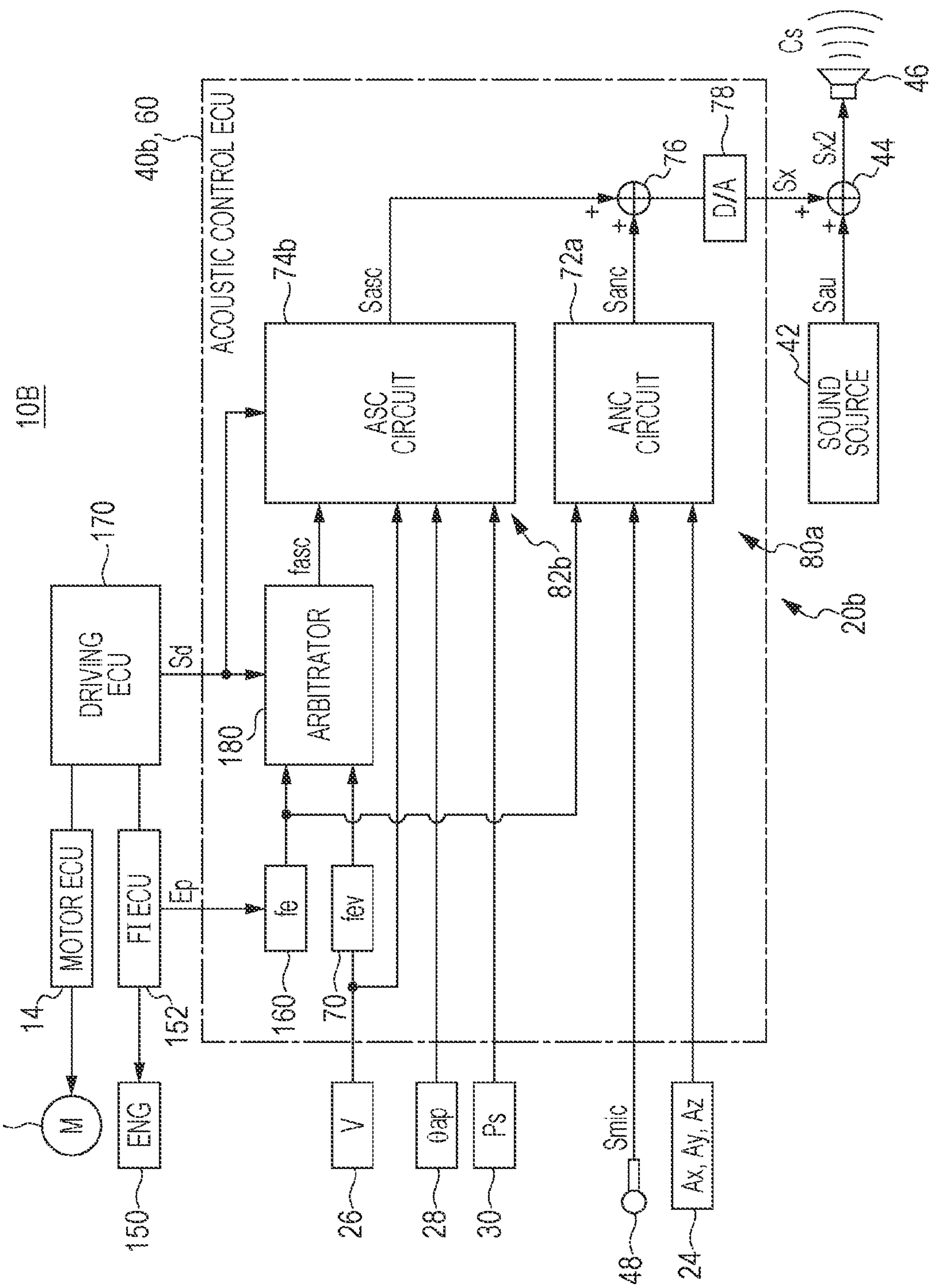

ENGINE ROTATIONAL FREQUENCY fe [Hz]
0
VEHICLE SPEED V [km/h]

FIG. 8


10B
DRIVING ECU
170
Sd
MOTOR ECU
14
FI ECU
152
Ep
M
12
ENG
150
ACOUSTIC CONTROL ECU
40b, 60
ARBITRATOR
180
fasc
fe
160
fev
70
ASC CIRCUIT
74b
Sasc
82b
ANC CIRCUIT
72a
Sanc
80a
SOUND SOURCE
42
Sau
20b
76
D/A
78
Sx
44
Sx2
46
Cs
V
26
θap
28
Ps
30
Smic
48
Ax, Ay, Az
24

ACTIVE SOUND EFFECT GENERATING APPARATUS

CROSS REFERENCES TO RELATED APPLICATIONS

The present application claims priority under 35 U.S.C. §119 to Japanese Patent Application No. 2014-115884, filed Jun. 4, 2014, entitled "Active sound effect generating apparatus." The contents of this application are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present disclosure relates to an active sound effect generating apparatus that generates a sound effect in accordance with the running state of a vehicle.

BACKGROUND

There is proposed an active sound effect generating apparatus (hereinafter also referred to as an "active sound control apparatus (ASC apparatus)") which detects an acceleration-deceleration operation by a driver and generates in a vehicle interior via an in-vehicle speaker a sound effect in accordance with the amount of acceleration-deceleration (for example, refer to Japanese Unexamined Patent Application Publication No. 2009-031428 and Japanese Unexamined Patent Application Publication No. 2013-167851).

In Japanese Unexamined Patent Application Publication No. 2009-031428, the amplitude of a control signal Sc is set by adjusting the amplitudes of reference signals Sr**1**, Sr**2**, and Sr**3** in accordance with an amount of change in rotational frequency Δaf [Hz/sec], which is a time differential value of an engine rotational frequency fe [Hz], and an accelerator opening degree Aor [%] (summary).

In Japanese Unexamined Patent Application Publication No. 2013-167851, a first gain GΔaf based on the amount of change in rotational frequency Δaf, which is the time differential value of the engine rotational frequency fe, and a shift position Ps is set (FIG. **1** and paragraph [0038]). In addition, a second gain Gfe based on the engine rotational frequency fe is set (paragraph [0039]). Furthermore, a third gain Gap based on an accelerator opening degree θap is set (paragraph [0040]). The product of the second gain Gfe and the third gain Gap is calculated and the calculated product is added to the first gain GΔaf to calculate a fourth gain Gcom (paragraphs [0044] and [0045]). A control signal Sc**2** (an amplitude adjustment control signal) is generated using the fourth gain Gcom (paragraph [0046]).

Vehicles that use continuously variable transmissions (CVTs) as transmissions and electric vehicles (for example, hybrid vehicles and strict battery-powered vehicles) that use motors as driving sources have been in widespread use in recent years.

In the case of a typical vehicle including a CVT, the variation in the engine rotational frequency may not follow the operation of an accelerator pedal on a road, such as a slope, even if the accelerator pedal is depressed by the driver. For example, when the accelerator pedal is suddenly depressed, a situation may occur in which the shift transmission by the CVT does not follow the operation of the accelerator pedal, the engine rotational frequency is increased first, and the vehicle speed is not immediately increased.

In such a case, the vehicle speed may not follow the amount of change in rotational frequency or the amount of

change in the accelerator opening degree in the configuration in which the amplitude of the sound effect is adjusted in accordance with the amount of change in rotational frequency and the accelerator opening degree, as in Japanese Unexamined Patent Application Publication No. 2009-031428 and Japanese Unexamined Patent Application Publication No. 2013-167851, thereby causing the driver to be concerned.

In electric vehicles, an engine is not as a driving source. In hybrid vehicles, there are cases in which the engine is stopped and the vehicle runs using only a motor. In the vehicles described above which do not use an engine at all or use an engine only temporarily as a driving source, it is difficult to apply the technologies in Japanese Unexamined Patent Application Publication No. 2009-031428 and Japanese Unexamined Patent Application Publication No. 2013-167851 in which the engine rotational frequency and the amount of change in rotational frequency, which is the time differential value of the engine rotational frequency, are used.

It is also desirable to resolve the above problems in the vehicles that use an engine without provided with the CVT considering common usage of the ASC apparatuses among several types of vehicles.

SUMMARY

It is desirable to provide an ASC apparatus capable of achieving at least one of generation of a more natural sounding sound effect and application to an electric vehicle.

One aspect of the present application describes an active sound effect generating apparatus including a waveform data table that stores pieces of waveform data corresponding to one waveform period; a vehicle speed detecting unit that detects a vehicle speed; a frequency setting unit that sets a vehicle speed corresponding frequency, which is defined on the basis of the vehicle speed detected by the vehicle speed detecting unit; a reference signal generating unit that generates a reference signal having a harmonic based on the vehicle speed corresponding frequency by sequentially reading the pieces of waveform data from the waveform data table; a control signal generating unit that generates a control signal used for generation of a sound effect on the basis of the reference signal; an output unit that outputs the control signal as the sound effect; an amount-of-change-in-frequency calculating unit that calculates an amount of change in frequency, which is a time differential value of the vehicle speed corresponding frequency; and a driving source load detecting unit that detects a load of a driving source of a vehicle. The control signal generating unit adjusts the amplitude of the control signal by varying the amplitude of the reference signal in accordance with the amount of change in frequency and the load of the driving source.

Thus, the vehicle speed corresponding frequency defined on the basis of the vehicle speed is set to calculate the amount of change in frequency, which is a time differential value of the vehicle speed corresponding frequency. The amplitude of the control signal is adjusted by varying the amplitude of the reference signal in accordance with the amount of change in frequency and the load of the driving source. Accordingly, for example, even if the increase in the vehicle speed is delayed from the increase in the engine rotational frequency when the accelerator pedal is suddenly depressed, the sound effect is generated in accordance with the amount of change in frequency based on the vehicle speed and the load of the driving source, in addition to or instead of the engine rotational frequency. This allows the sound effect more appropriate for the behavior of the vehicle to be produced.

In addition, it is possible to produce the sound effect appropriate for the behavior of the vehicle even when the vehicle is an electric vehicle that is not provided with an engine serving as the driving source.

A frequency, which is a fundamental frequency, may be set in advance in accordance with the vehicle speed in the frequency setting unit. In this case, it is possible to represent a dominant portion in the sound effect at the fundamental frequency corresponding to the vehicle speed. Accordingly, it is possible to generate the more natural sound effect for the driver.

When the vehicle is a hybrid vehicle including an engine and a motor as the driving sources, the active sound effect generating apparatus may further include a rotational frequency detecting unit that detects a rotational frequency of the engine; and an amount-of-change-in-rotational frequency calculating unit that calculates an amount of change in rotational frequency, which is a time differential value of the rotational frequency. The driving source load detecting unit may detect a load of the engine. The reference signal generating unit may generate the reference signal on the basis of the rotational frequency of the engine when only the engine is in a driving state and the reference signal generating unit may generate the reference signal on the basis of an arbitration frequency resulting from arbitration or selection of the vehicle speed corresponding frequency and the rotational frequency of the engine when both the engine and the motor are in the driving state. With the above configuration, it is possible to appropriately output the sound effect even if the operation state of the driving source is varied in the hybrid vehicle.

Another aspect of the present application describes an active sound effect generating apparatus including a waveform data table that stores pieces of waveform data corresponding to one waveform period; a rotational frequency detecting unit that detects a rotational frequency of an engine; a reference signal generating unit that generates a reference signal having a harmonic based on the rotational frequency by sequentially reading the pieces of waveform data from the waveform data table; a control signal generating unit that generates a control signal used for generation of a sound effect on the basis of the reference signal; an output unit that outputs the control signal as the sound effect; an amount-of-change-in-rotational-frequency calculating unit that calculates an amount of change in rotational frequency, which is a time differential value of the rotational frequency; an engine load detecting unit that detects a load of the engine; and a vehicle speed detecting unit that detects a vehicle speed. The control signal generating unit adjusts the amplitude of the control signal by varying the amplitude of the reference signal in accordance with the amount of change in rotational frequency, the load of the engine, and the vehicle speed. The amplitude of the control signal is set so as to be decreased with the decreasing vehicle speed detected by the vehicle speed detecting unit.

Thus, the amplitude of the control signal is adjusted by varying the amplitude of the reference signal in accordance with the amount of change in rotational frequency, which is a time differential value of the rotational frequency of the engine, the load of the driving source, and the vehicle speed. Accordingly, for example, even if the increase in the vehicle speed is delayed from the increase in the rotational frequency of the engine when the accelerator pedal is suddenly depressed, the sound effect is generated in accordance with the amount of change in rotational frequency, the load of the driving source, and the vehicle speed, in addition to the engine rotational frequency. This allows the sound effect more appropriate for the behavior of the vehicle to be produced.

According to the present disclosure, it is possible to achieve at least one of generation of a more natural sound effect and application to an electric vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages of the disclosure will become apparent in the following description taken in conjunction with the following drawings.

FIG. **1** schematically illustrates an exemplary configuration of a vehicle including an active sound effect generating apparatus (hereinafter referred to as an "ASC apparatus") according to a first embodiment of the present disclosure.

FIG. **2** illustrates the ASC apparatus according to the first embodiment and an exemplary schematic circuit configuration around the ASC apparatus.

FIG. **3** schematically illustrates an exemplary configuration of a vehicle including an ASC apparatus according to a second embodiment of the present disclosure.

FIG. **4** illustrates the ASC apparatus according to the second embodiment and an exemplary schematic circuit configuration around the ASC apparatus.

FIG. **5** illustrates an example of time series data about an accelerator opening degree, an engine rotational frequency, and a vehicle speed when the ASC apparatus according to the second embodiment and a sound effect generating apparatus according to a comparative example are used.

FIG. **6** illustrates an example of the relationship between the vehicle speed, the engine rotational frequency, and a sound pressure level of a control sound (sound effect) when the sound effect generating apparatus according to the comparative example is used.

FIG. **7** illustrates an example of the relationship between the vehicle speed, the engine rotational frequency, and the sound pressure level of the control sound (sound effect) when the ASC apparatus according to the second embodiment is used.

FIG. **8** schematically illustrates an exemplary configuration of a vehicle including an ASC apparatus according to a third embodiment of the present disclosure.

DETAILED DESCRIPTION

A. First Embodiment

A1. Entire Configuration and Configuration of Each Component

A1-1. Entire Configuration

FIG. **1** schematically illustrates an exemplary configuration of a vehicle **10** including an active sound effect generating apparatus **82** (hereinafter referred to as an "ASC apparatus **82**") according to a first embodiment of the present disclosure. FIG. **2** illustrates the ASC apparatus **82** according to the first embodiment and an exemplary schematic circuit configuration around the ASC apparatus **82**. The vehicle **10** is an electric vehicle including a driving motor **12** (hereinafter also referred to as a "motor **12**") serving as a driving source (especially, an electric vehicle including only the motor **12** as the driving source). The motor **12** is controlled by a motor electronic control unit **14** (hereinafter referred to as a "motor ECU **14**").

The vehicle **10** includes an acoustic system **20**, multiple front-wheel suspensions **22***a*, multiple rear-wheel suspensions **22***b*, multiple acceleration sensor units **24** provided in the front-wheel suspensions **22***a*, a vehicle speed sensor **26**, an accelerator position sensor **28**, and a gear shift position sensor **30**, in addition to the motor **12** and the motor ECU **14**.

The acceleration sensor units **24** detect vibration accelerations Ax, Ay, and Az [mm/s/s] of the front-wheel suspensions **22***a* in a front-back direction (an X direction in FIG. **1**), a left-right direction (a Y direction in FIG. **1**), and an up-down direction (a Z direction in FIG. **1**) of the vehicle **10** and supply the detected vibration accelerations Ax, Ay, and Az to the acoustic system **20**.

The vehicle speed sensor **26** detects a vehicle speed V [km/h] of the vehicle **10**. The accelerator position sensor **28** detects an amount of operation of an accelerator pedal **32** (hereinafter referred to as an "accelerator opening degree θap") [deg]. The gear shift position sensor **30** detects the position of a shift lever (not illustrated) (hereinafter referred to as a "shift position Ps").

A1-2. Acoustic System **20**

A1-2-1. Entire Configuration of Acoustic System **20**

The acoustic system **20** has a function to receive and output a radio broadcast program, to play back music, etc. (an audio function), a function to perform active noise control (an active noise control function or an ANC function), and a function to perform active sound effect generation control (an active sound effect generation control function or an ASC function).

In order to realize the above functions, the acoustic system **20** includes an acoustic control electronic control unit **40** (hereinafter referred to as an "acoustic control ECU **40**" or an "ECU **40**"), a sound source **42**, an adder **44**, a speaker **46**, and a microphone **48**. An amplifier (not illustrated) may be provided between the adder **44** and the speaker **46**.

The ECU **40** selectively realizes the ANC function and the ASC function, among the three functions of the acoustic system **20**, and supplies a control signal Sx, which is an output from the acoustic system **20**, to the adder **44**.

When the ANC function, of the ANC function and the ASC function, is being performed, the control signal Sx output from the ECU **40** defines a cancellation sound to cancel a noise (a road noise NZr) occurring in the vehicle interior due to contact between wheels **50** and a road surface **300** while the vehicle **10** is running. When the ASC function is being performed, the control signal Sx defines a sound effect (a pseudo engine sound) equivalent to a noise (a muffled engine sound) occurring in the vehicle interior in response to an operation (vibration) of an engine. As described above, the vehicle **10** of the first embodiment includes only the motor **12** as the driving source and does not include an engine. Accordingly, the pseudo engine sound is a sound effect output from the speaker **46** if an engine is installed in the vehicle **10**. Another sound effect (for example, a pseudo motor sound) may be output, instead of the pseudo engine sound. The acoustic system **20** will be described in detail below.

The sound source **42** is composed of an audio device and a navigation apparatus. The sound source **42** supplies an audio signal Sau that defines, for example, music or audio routing assistance to the adder **44**.

The adder **44** adds the control signal Sx from the ECU **40** to the audio signal Sau from the sound source **42** to generate a control signal Sx**2** and supplies the control signal Sx**2** to the speaker **46**.

The speaker **46** is provided at a front seat **52** (a driver seat) side of the vehicle **10** (for example, in a front door panel at each side, in a kick panel at each side (for example, in the inside of the door near a driver leg space), or in the roof above the driver seat). The speaker **46** supplies a control sound CS defined by the control signal Sx**2** from the adder **44** to a driver **302** (occupant). Accordingly, the control sound CS is output as the cancellation sound cancelling the road noise NZr when the ECU **40** is performing the ANC function and the control sound CS is output as the sound effect (pseudo engine sound) when the ECU **40** is performing the ASC function. The speaker **46** may be provided at a rear seat **54** side, in addition to the front seat **52** side.

The microphone **48** is disposed at a position (evaluation position) near the position of an ear of the driver **302** to detect a sound at the position. The microphone **48** generates an electrical signal (a microphone signal Smic) corresponding to the detected sound and supplies the microphone signal Smic to the ECU **40**. The sound detected by the microphone **48** when the ECU **40** is performing the ANC function is a residual noise remaining after an interior sound, such as the muffled engine sound, has been cancelled out by the cancellation sound. In this case, the microphone signal Smic is an error signal indicating the residual noise.

A1-2-2. Acoustic Control ECU **40**

A1-2-2-1. Entire Configuration of Acoustic Control ECU **40**

As described above, the ECU **40** selectively performs an ANC process and an ASC process. The ECU **40** includes an embedded computer **60** and a memory **62** (FIG. **1**), which are hardware components. The embedded computer **60** is capable of performing the functions including the ANC function and the ASC function with a dedicated circuit or through software processes.

As illustrated in FIG. **2**, the ECU **40** includes a virtual engine rotational frequency setter **70** (hereinafter also referred to as a "fev setter **70**"), an ANC circuit **72**, an ASC circuit **74**, an adder **76**, and a digital-to-analog converter **78** (hereinafter also referred to as a "D/A converter **78**").

The acceleration sensor units **24**, the speaker **46**, the microphone **48**, and the ANC circuit **72** compose an active noise control apparatus **80** (hereinafter referred to as an "ANC apparatus **80**"). The vehicle speed sensor **26**, the accelerator position sensor **28**, the gear shift position sensor **30**, the speaker **46**, and the ASC circuit **74** compose the ASC apparatus **82**.

The selection between the ANC apparatus **80** and the ASC apparatus **82** (that is, the selection between an output from the ANC circuit **72** and an output from the ASC circuit **74**) is performed through a switching determination process (not illustrated). Accordingly, the control signal Sx output from the acoustic control ECU **40** corresponds to either of the output signal (control signal Sanc) from the ANC circuit **72** or the output signal (control signal Sasc) from the ASC circuit **74**.

A1-2-2-2. fev Setter **70**

The fev setter **70** sets a virtual engine rotational frequency fev (hereinafter also referred to as a "virtual frequency fev")

[Hz] in accordance with the vehicle speed V and supplies the virtual frequency fev to the ASC circuit **74**. The virtual frequency fev means the rotational frequency of an engine (virtual engine) if an engine is installed in the vehicle **10**. In the first embodiment, the virtual frequency fev is set on the basis of the vehicle speed V.

A frequency, which is a fundamental frequency, is set in advance in accordance with the vehicle speed V in the fev setter **70**. In other words, the fev setter **70** includes a map in which the relationship between the vehicle speed V and the fundamental frequency is set in advance. For example, when the vehicle speed V has a value of V**1**, the fev setter **70** stores a fundamental frequency fev**1** in advance. Accordingly, for example, the value of the fundamental frequency is identified upon identification of the vehicle speed V. One fundamental frequency or multiple fundamental frequencies are selected depending on the vehicle speed V.

A1-2-2-3. ANC Circuit 72

As described above, the ANC circuit **72** performs the ANC function. For example, a specific configuration of the ANC circuit **72** is described in, for example, Japanese Unexamined Patent Application Publication No. 2012-131315, the entire contents of which are incorporated herein by reference.

A1-2-2-4. ASC Circuit 74

A1-2-2-4-1. Summary of ASC Circuit 74

The ASC circuit **74** generates the sound effect, which is a virtual muffled engine sound, to improve the acoustic effect in the vehicle interior, for example, by enhancing the variation in speed of the vehicle **10**.

As illustrated in FIG. **2**, the control signal Sasc from the ASC circuit **74** is added to the control signal Sanc from the ANC circuit **72** in the adder **76**. As described above, the ANC circuit **72** and the ASC circuit **74** operate selectively. Accordingly, the control signal Sx output from the adder **76** is equal to the control signal Sasc from the ASC circuit **74** or the control signal Sanc from the ANC circuit **72**.

A1-2-2-4-2. Entire Configuration of ASC Circuit 74

As illustrated in FIG. **2**, the ASC circuit **74** includes a control signal generator **98** (part of a control signal generating unit) including harmonic multipliers **84***a*, **84***b*, and **84***c*, reference signal generators **86***a*, **86***b*, and **86***c*, a waveform data table **88**, first acoustic correctors **90***a*, **90***b*, and **90***c*, second acoustic correctors **92***a*, **92***b*, and **92***c*, third acoustic correctors **94***a*, **94***b*, and **94***c*, and an adder **96**; an amount-of-change-in-frequency detector **100** (hereinafter also referred to as a "Δafv detector **100**"); and a total-sound-volume corrector **102**. The components in the ASC circuit **74** are similar to those described in, for example, Japanese Unexamined Patent Application Publication No. 2013-167851 or Japanese Unexamined Patent Application Publication No. 2006-301598, and its corresponding US 2006/0215846 the entire contents of which are incorporated herein by reference.

Each of the harmonic multipliers **84***a*, **84***b*, and **84***c* generates a harmonic signal having a frequency of a certain order (certain multiple) of the virtual engine rotational frequency fev. Specifically, the harmonic multiplier **84***a* generates the 0_1 order (for example, second) harmonic signal, the harmonic multiplier **84***b* generates the 0_2 order (for example, third) harmonic signal, and the harmonic multiplier **84***c* generates the 0_3 order (for example, fourth) harmonic signal.

The reference signal generators **86***a*, **86***b*, and **86***c* generate reference signals Sr**1**, Sr**2**, and Sr**3**, respectively, using the harmonic signals from the harmonic multipliers **84***a*, **84***b*, and **84***c* and waveform data stored in the waveform data table **88** and supply the generated reference signals Sr**1**, Sr**2**, and Sr**3** to the first acoustic correctors **90***a*, **90***b*, and **90***c*, respectively.

The first acoustic correctors **90***a*, **90***b*, and **90***c* perform flattening to generate the control sound CS, which is the sound effect having a sense of linearity for the acceleration operation, in an ear of the driver **302** (refer to paragraphs [0044] to [0051] in Japanese Unexamined Patent Application Publication No. 2006-301598). The second acoustic correctors **92***a*, **92***b*, and **92***c* perform frequency enhancement to enhance only a desired frequency in the control sound CS, which is the sound effect (refer to paragraphs [0054] to [0057] in Japanese Unexamined Patent Application Publication No. 2006-301598). The third acoustic correctors **94***a*, **94***b*, and **94***c* perform correction for every order to correct the reference signals Sr**1**, Sr**2**, and Sr**3** depending on the orders (refer to paragraph [0063] in Japanese Unexamined Patent Application Publication No. 2006-301598).

The reference signals Sr**1**, Sr**2**, and Sr**3** through the first acoustic correctors **90***a*, **90***b*, and **90***c*, the second acoustic correctors **92***a*, **92***b*, and **92***c*, and the third acoustic correctors **94***a*, **94***b*, and **94***c* are added to each other in the adder **96**, thereby generating a control signal Sc**1**.

The configuration of the control signal generator **98** is not limited to the above one and may be appropriately varied. For example, the control signal generator **98** may be composed of any one kind or any two kinds of the first acoustic correctors **90***a*, **90***b*, and **90***c*, the second acoustic correctors **92***a*, **92***b*, and **92***c*, and the third acoustic correctors **94***a*, **94***b*, and **94***c*.

The Δafv detector **100** detects a time differential value of the virtual frequency fev (hereinafter also referred to as an "amount-of-change-in virtual engine rotational frequency Δafv" or an "amount-of-change-in-frequency Δafv") [Hz/s] on the basis of the virtual frequency fev from the fev setter **70** and supplies the amount-of-change-in virtual engine rotational frequency Δafv to the total-sound-volume corrector **102**.

The total-sound-volume corrector **102** (part of the control signal generating unit) corrects the volume of the control sound CS (sound effect) in accordance with the virtual frequency fev, the amount-of-change-in virtual engine rotational frequency Δafv, the accelerator opening degree θap, and the shift position Ps.

A1-2-2-4-3. Detailed Description of Total-Sound-Volume Corrector 102

As described above, the total-sound-volume corrector **102** corrects the volume of the control sound CS (sound effect) output from the speaker **46** in accordance with the virtual frequency fev, the amount-of-change-in-frequency Δafv, the accelerator opening degree θap, and the shift position Ps.

As illustrated in FIG. **2**, the total-sound-volume corrector **102** includes a first gain setter **110**, a second gain setter **112**, a third gain setter **114**, a multiplier **116**, an adder **118**, and a total-sound-volume correction filter **120**.

The first gain setter **110** sets a gain based on the shift position Ps and the amount-of-change-in-frequency Δafv (such a gain is hereinafter referred to as an "amount-of-change-in-frequency gain GΔafv" or a "first gain GΔafv"). More specifically, a map in which the relationship between the amount-of-change-in-frequency Δafv and the first gain GΔafv is defined is set in advance for each shift position Ps (a combination of first, second, and third or a combination of a D range and a B range). The first gain setter **110** switches the map on the basis of the shift position Ps notified from the gear shift position sensor **30**. Then, the first gain setter **110** sets the first gain GΔafv on the basis of the amount-of-change-in-frequency Δafv from the Δafv detector **100**. The first gain setter **110** may be configured so as not to use the shift position Ps.

The second gain setter **112** sets a gain based on the virtual engine rotational frequency fev (such a gain is hereinafter referred to as a "frequency gain Gfev" or a "second gain Gfev"). More specifically, a map in which the relationship between the virtual frequency fev and the second gain Gfev is defined is set in advance. The second gain setter **112** sets the second gain Gfev on the basis of the virtual frequency fev from the fev setter **70**.

The third gain setter **114** sets a gain based on the accelerator opening degree θap (such a gain is hereinafter referred to as an "accelerator opening degree gain Gap" or a "third gain Gap"). More specifically, a map in which the relationship between the accelerator opening degree θap and the third gain Gap is defined is set in advance. The third gain setter **114** sets the third gain Gap on the basis of the accelerator opening degree θap detected by the accelerator position sensor **28**.

The multiplier **116** multiplies the second gain Gfev (frequency gain Gfev) set by the second gain setter **112** by the third gain Gap (accelerator opening degree gain Gap) set by the third gain setter **114** and supplies the result of the multiplication to the adder **118**.

The adder **118** (fourth gain setter) adds the first gain GΔafv (amount-of-change-in-frequency gain GΔafv) set by the first gain setter **110** to the product of the second gain Gfev and the third gain Gap, calculated in the multiplier **116**, to calculate a common correction gain Gcom (hereinafter also referred to as a "fourth gain Gcom").

The total-sound-volume correction filter **120** multiplies the control signal Sc**1** from the adder **96** by the fourth gain Gcom calculated by the adder **118** to generate the control signal Sasc (amplitude adjustment control signal). The total-sound-volume correction filter **120** supplies the generated control signal Sasc to the adder **76**.

A2. Advantages in First Embodiment

As described above, according to the first embodiment, the virtual engine rotational frequency fev (vehicle speed corresponding frequency) defined on the basis of the vehicle speed V is set to calculate the amount-of-change-in-frequency Δafv, which is the time differential value of the virtual frequency fev (FIG. **2**). The amplitude of the control signal Sc**1** (the amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3**) is varied in accordance with the amount-of-change-in-frequency Δafv and the accelerator opening degree θap (the load of the driving source) to adjust the amplitude of the control signal Sasc (FIG. **2**). This allows the sound effect appropriate for the behavior of the vehicle **10** to be produced even when the vehicle **10** is an electric vehicle that is not provided with the engine serving as the driving source.

In the first embodiment, the frequency, which is the fundamental frequency, is set in advance in accordance with the vehicle speed V in the fev setter **70** (frequency setting unit). This allows a dominant portion in the control sound CS serving as the sound effect to be represented at the fundamental frequency corresponding to the vehicle speed V. Accordingly, it is possible to generate the more natural sound effect for the driver **302**.

B. Second Embodiment

B1. Entire Configuration and Configuration of Each Component (Difference from First Embodiment)

B1-1. Entire Configuration

FIG. **3** schematically illustrates an exemplary configuration of a vehicle **10**A including an active sound effect generating apparatus **82***a* (hereinafter referred to as an "ASC apparatus **82***a*") according to a second embodiment of the present disclosure. FIG. **4** illustrates the ASC apparatus **82***a* according to the second embodiment and an exemplary schematic circuit configuration around the ASC apparatus **82***a*. The same reference numerals are used in the second embodiment to identify the same components in the first embodiment. A description of such components is omitted herein.

The vehicle **10** of the first embodiment is the electric vehicle including the driving motor **12** as the driving source while the vehicle **10**A of the second embodiment is a vehicle including an engine **150** as the driving source. The engine **150** is controlled by a fuel injection electronic control unit **152** (hereinafter referred to as an "FI ECU **152**"). In addition, the engine **150** is connected to a continuously variable transmission **154** (hereinafter referred to as a "CVT **154**"). A transmission gear ratio or the like of the CVT **154** is controlled by a CVT electronic control unit (CVT ECU) (not illustrated).

The ANC function performed by the acoustic system **20** of the first embodiment is targeted at the road noise NZr. In contrast, the ANC function performed by an acoustic system **20***a* of the second embodiment is targeted at not only the road noise NZr but also a noise (muffled engine sound NZe) occurring in the vehicle interior in response to the operation (vibration) of the engine **150**.

The reference signals Sr**1**, Sr**2**, and Sr**3** are generated on the basis of the vehicle speed V (the virtual engine rotational frequency fev) with the ASC function performed by the acoustic system **20** of the first embodiment (FIG. **2**). In other words, the vehicle speed V is used for the generation of the reference signals Sr**1**, Sr**2**, and Sr**3**. In contrast, the reference signals Sr**1**, Sr**2**, and Sr**3** are generated on the basis of an engine pulse Ep (an engine rotational frequency fe) output from the FI ECU **152** with the ASC function performed by the acoustic system **20***a* of the second embodiment. In addition, in the acoustic system **20***a* of the second embodiment, the amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3** (or the amplitude of the control signal Sc**1** based on the reference signals Sr**1**, Sr**2**, and Sr**3**) are adjusted on the basis of the vehicle speed V.

B1-2. Acoustic System 20*a*

B1-2-1. Entire Configuration of Acoustic System 20*a*

The acoustic system **20***a* of the second embodiment differs from the acoustic system **20** of the first embodiment in that the acoustic system **20***a* of the second embodiment includes an acoustic control electronic control unit **40***a* (hereinafter referred to as an "acoustic control ECU **40***a*" or an "ECU **40***a*"), instead of the ECU **40** of the first embodiment.

B1-2-2. Acoustic Control ECU **40***a*

As illustrated in FIG. **4**, the ECU **40***a* includes an engine rotational frequency detector **160** (hereinafter also referred to as a "fe detector **160**"), an ANC circuit **72***a*, an ASC circuit **74***a*, the adder **76**, and the digital-to-analog converter **78** (hereinafter also referred to as the "D/A converter **78**").

The acceleration sensor units **24**, the speaker **46**, the microphone **48**, the ANC circuit **72***a*, and the fe detector **160** compose an active noise control apparatus **80***a* (hereinafter referred to as an "ANC apparatus **80***a*"). The vehicle speed sensor **26**, the accelerator position sensor **28**, the gear shift position sensor **30**, the speaker **46**, the ASC circuit **74***a*, and the fe detector **160** compose the ASC apparatus **82***a*.

B1-2-3. fe Detector **160**

The fe detector **160** detects the engine rotational frequency fe [Hz] on the basis of the engine pulse Ep from the FI ECU **152**. The fe detector **160** supplies the detected engine rotational frequency fe to the ANC circuit **72***a* and the ASC circuit **74***a*.

The virtual engine rotational frequency fev is used in the first embodiment (FIG. **2**). In contrast, the engine rotational frequency fe, which is an actual rotational frequency of the engine **150**, is used in the second embodiment.

B1-2-4. ANC Circuit **72***a*

As described above, the ANC function performed by the ANC circuit **72***a* of the second embodiment is targeted at not only the road noise NZr but also the noise (muffled engine sound NZe) occurring in the vehicle interior in response to the operation (vibration) of the engine **150**. For example, a specific configuration of the ANC circuit **72***a* is described in, for example, Japanese Unexamined Patent Application Publication No. 2012-131315 or Japanese Unexamined Patent Application Publication No. 2004-361721, and its corresponding US 2004/0247137 the entire contents of which are incorporated herein by reference.

B1-2-5. ASC Circuit **74***a*

The ASC circuit **74***a* of the second embodiment basically has the same configuration as that of the ASC circuit **74** of the first embodiment. However, an amount-of-change-in-frequency detector **100***a* (hereinafter also referred to as a "Δaf detector **100***a*") and a total-sound-volume corrector **102***a* in the ASC circuit **74***a* differ from the Δafv detector **100** and the total-sound-volume corrector **102** in the ASC circuit **74**, respectively.

The Δaf detector **100***a* detects a time differential value of the engine rotational frequency fe (hereinafter also referred to as an "amount-of-change-in engine rotational frequency Δaf" or an "amount-of-change-in-frequency Δaf") [Hz/s] on the basis of the engine rotational frequency fe from the fe detector **160** and supplies the amount-of-change-in engine rotational frequency Δaf to the total-sound-volume corrector **102***a*.

The total-sound-volume corrector **102***a* corrects the volume of the control sound CS (sound effect) in accordance with the engine rotational frequency fe, the amount-of-change-in engine rotational frequency Δaf, the accelerator opening degree θap, and the shift position Ps.

As illustrated in FIG. **4**, the total-sound-volume corrector **102***a* includes a first gain setter **110***a*, a second gain setter **112***a*, the third gain setter **114**, a fourth gain setter **162**, the multiplier **116**, a multiplier **164**, the adder **118**, and the total-sound-volume correction filter **120**.

The first gain setter **110***a* sets a gain based on the shift position Ps and the amount-of-change-in-frequency Δaf (such a gain is hereinafter referred to as an "amount-of-change-in-frequency gain GΔaf" or a "first gain GΔaf"), as in the first gain setter **110**.

The second gain setter **112***a* sets a gain based on the engine rotational frequency fe (such a gain is hereinafter referred to as a "frequency gain Gfe" or a "second gain Gfe"), as in the second gain setter **112**.

The fourth gain setter **162** sets a gain based on the vehicle speed V (such a gain is hereinafter referred to as a "vehicle speed gain Gv"). More specifically, a map in which the relationship between the vehicle speed V and the vehicle speed gain Gv is defined is set in advance. The fourth gain setter **162** sets the vehicle speed gain Gv on the basis of the vehicle speed V detected by the vehicle speed sensor **26**.

The multiplier **164** multiplies the accelerator opening degree gain Gap set by the third gain setter **114** by the vehicle speed gain Gv set by the fourth gain setter **162** and supplies the result of the multiplication to the multiplier **116**. Accordingly, the vehicle speed V is reflected in the outputs from the multiplier **116** and the adder **118** and the common correction gain Gcom used in the total-sound-volume correction filter **120**.

B2. Exemplary Data when Second Embodiment is Used

FIG. **5** illustrates an example of time series data about the accelerator opening degree θap, the engine rotational frequency fe, and the vehicle speed V when the ASC apparatus **82***a* according to the second embodiment and a sound effect generating apparatus according to a comparative example are used. FIG. **6** illustrates an example of the relationship between the vehicle speed V, the engine rotational frequency fe, and a sound pressure level Ls [dB] of the control sound CS (sound effect) when the sound effect generating apparatus according to the comparative example is used. FIG. **7** illustrates an example of the relationship between the vehicle speed V, the engine rotational frequency fe, and the sound pressure level Ls [dB] of the control sound CS (sound effect) when the ASC apparatus **82***a* according to the second embodiment is used.

The comparative example has, for example, the configuration described in Japanese Unexamined Patent Application Publication No. 2013-167851 and the gain adjustment in accordance with the vehicle speed V is not performed in the comparative example. Solid lines in FIG. **6** and FIG. **7** illustrate the control sounds CS (sound effects) the sound pressure levels Ls of which exceed a certain sound pressure level threshold value.

In the example in FIG. **5**, the accelerator opening degree θap starts to increase at a time t**1**, sharply increases from a time t**2** to a time t**3**, and subsequently decreases. After a time t**5**, the accelerator opening degree θap is kept at a substantially equal value. The engine rotational frequency fe sharply increases from the time t**2** to a time t**4** and is subsequently kept at a substantially equal value. The vehicle speed V continuously increases from the time t**1** to the time t**5**. However, the vehicle speed V increases gradually, compared with the accelerator opening degree θap. After the time **t3**, the accelerator opening degree θap decreases or is hardly varied while the vehicle speed V continues to increase.

In the case of the comparative example (FIG. **6**), the sound pressure level Ls of the control sound CS (sound effect) is set in accordance with the engine rotational frequency fe. In other words, the solid lines (the engine rotational frequencies fe corresponding to the sound pressure levels Ls exceeding the sound pressure level threshold value) in FIG. **6** are hardly varied with the increase in the vehicle speed V. Accordingly, when the example in FIG. **5** is applied to the comparative example, the sound pressure level Ls increases from the time **t1** to the time **t3** but the sound pressure level Ls is kept at a constant value or decreases after the time **t3**.

In contrast, in the case of the second embodiment (FIG. **7**), the sound pressure level Ls of the control sound CS is set in accordance with the vehicle speed V, in addition to the engine rotational frequency fe (FIG. **4**). In other words, the solid lines in FIG. **7** indicate that the engine rotational frequencies fe corresponding to the sound pressure levels Ls exceeding the sound pressure level threshold value increase in response to the increase in the vehicle speed V. Accordingly, when the example in FIG. **5** is applied to the second embodiment, the increase in the vehicle speed V is capable of being reflected in the sound pressure level Ls while the vehicle speed V is increasing from the time **t1** to the time **t5** and after the time **t5**. For example, it is possible to continuously increase the sound pressure level Ls from the time **t1** to the time **t5**. Alternatively, it is possible to keep the sound pressure level Ls or slow down the decrease in the sound pressure level Ls even after the time **t3** at which the accelerator opening degree θap starts to decrease or even after the time **t5** at which the engine rotational frequency fe is kept at a substantially constant value.

B3. Advantages in Second Embodiment

The ASC apparatus **82***a* according to the second embodiment has the following advantages, in addition to or instead of the advantages in the first embodiment.

According to the second embodiment, the amplitude of the control signal Sasc is adjusted by varying the amplitude of the control signal Sc**1** (the amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3**) in accordance with the amount-of-change-in-frequency Δaf, the accelerator opening degree θap (the load of the driving source), and the vehicle speed V (FIG. **4**). Accordingly, for example, even if the increase in the vehicle speed V is delayed from the increase in the engine rotational frequency fe when the accelerator pedal **32** is suddenly depressed, the sound effect is generated in accordance with the amount-of-change-in-frequency Δaf based on the vehicle speed V and the load of the engine **150**, in addition to the engine rotational frequency fe. This allows the sound effect more appropriate for the behavior of the vehicle **10**A to be produced.

In particular, the vehicle **10**A of the second embodiment includes the CVT **154** (FIG. **3**). When the vehicle **10**A includes the CVT **154**, the variation in the engine rotational frequency fe may not follow the operation of the accelerator pedal **32** on a road, such as a slope, even if the accelerator pedal **32** is depressed by the driver **302**. For example, when the accelerator pedal **32** is suddenly depressed, a situation may occur in which the shift transmission by the CVT **154** does not follow the operation of the accelerator pedal **32**, the engine rotational frequency fe is increased first, and the vehicle speed V is not immediately increased.

According to the second embodiment, the sound effect is generated in accordance with the amount-of-change-in-frequency Δaf based on the vehicle speed V and the load of the engine **150**, in addition to the engine rotational frequency fe. Accordingly, it is possible to resolve the above problems in the vehicle **10**A including the CVT **154** to produce the sound effect more appropriate for the behavior of the vehicle **10**A.

C. Third Embodiment

C1. Entire Configuration and Configuration of Each Component (Difference from First and Second Embodiments)

C1-1. Entire Configuration

FIG. **8** schematically illustrates an exemplary configuration of a vehicle **10**B including an active sound effect generating apparatus **82***b* (hereinafter referred to as an "ASC apparatus **82***b*") according to a third embodiment of the present disclosure. The same reference numerals are used in the third embodiment to identify the same components in the first and second embodiments. A description of such components is omitted herein.

The vehicle **10** of the first embodiment is an electric vehicle including the motor **12** as the driving source (FIG. **1**) and the vehicle **10**A of the second embodiment is a vehicle including the engine **150** as the driving source (FIG. **3**). In contrast, the vehicle **10**B of the third embodiment is a so-called hybrid vehicle including the motor **12** and the engine **150** as the driving sources (FIG. **8**). The motor **12** is controlled by the motor ECU **14** and the engine **150** is controlled by the FI ECU **152**. Selection between the motor **12** and the engine **150** as the driving source is performed by a driving electronic control unit **170** (hereinafter referred to as a "driving ECU **170**"). The vehicle **10**B may include the CVT **154** similar to that in the second embodiment, although not illustrated in FIG. **8**.

An acoustic system **20***b* of the third embodiment switches the acoustic control (switching between the ANC process and the ASC process) in accordance with the driving state of the driving sources composed of the motor **12** and the engine **150**.

C1-2. Driving ECU 170

The driving ECU **170** controls the outputs from the motor **12** and the engine **150** on the basis of the outputs from the various sensors and the respective electronic control units (hereinafter referred to as "ECUs"). The driving ECU **170** includes an input-output portion, an arithmetic portion, and a storage portion (not illustrated).

The various sensors from which the driving ECU **170** receives the outputs include, for example, the vehicle speed sensor **26**, the accelerator position sensor **28**, and the gear shift position sensor **30**.

C1-3. Acoustic System 20*b*

C1-3-1. Entire Configuration of Acoustic System 20*b*

An acoustic control electronic control unit **40***b* (hereinafter referred to as an "acoustic control ECU **40***b*") in the acoustic system **20***b* of the third embodiment includes the fev setter **70** as in the first embodiment, the fe detector **160** as in the second embodiment, an arbitrator **180**, the ANC circuit **72***a*, an ASC circuit **74***b*, the adder **76**, and the D/A converter **78**.

The virtual engine rotational frequency fev from the fev setter **70** is supplied to the arbitrator **180**. The engine rotational frequency fe from the fe detector **160** is supplied to the ANC circuit **72***a* and the arbitrator **180**.

C1-3-2. Arbitrator **180**

The arbitrator **180** generates a sound effect frequency fasc on the basis of the virtual frequency fev from the fev setter **70** and the engine rotational frequency fe from the fe detector **160** and supplies the sound effect frequency fasc to the ASC circuit **74***b*. The processing in the arbitrator **180** will be described in detail below.

C1-3-3. ANC Circuit **72***a*

The ANC circuit **72***a* and the ANC apparatus **80***a* in the third embodiment are the same as those in the second embodiment. The ASC circuit **74***b* is a combination of the ASC circuit **74** (FIG. **2**) of the first embodiment and the ASC circuit **74***a* (FIG. **4**) of the second embodiment. The vehicle speed sensor **26**, the accelerator position sensor **28**, the gear shift position sensor **30**, the speaker **46**, the fev setter **70**, the ASC circuit **74***b*, the fe detector **160**, and the arbitrator **180** compose the active sound effect generating apparatus **82***b* (hereinafter referred to as the "ASC apparatus **82***b*").

C1-3-4. ASC Circuit **74***b*

The ASC circuit **74***b* may have, for example, the same configuration as that of the ASC circuit **74***a* of the second embodiment. In this case, the Δaf detector **100***a* and so on in the ASC circuit **74***b* performs the processing using the sound effect frequency fasc, instead of the engine rotational frequency fe.

Alternatively, the ASC circuit **74***b* may identify the driving state of the vehicle **10**B on the basis of a driving state signal Sd from the driving ECU **170** (selection of the driving source) and may perform the processing corresponding to the driving state.

Specifically, when only the motor **12** is selected as the driving source of the vehicle **10**B, the ASC circuit **74***b* selects and uses the ASC circuit **74**, which is the same as that in the first embodiment. In this case, the Δafv detector **100** and so on in the ASC circuit **74** performs the processing using the sound effect frequency fasc, instead of the virtual frequency fev.

When the combination of the motor **12** and the engine **150** or only the engine **150** is selected as the driving source of the vehicle **10**B, the ASC circuit **74***b* selects and uses the ASC circuit **74***a*, which is the same as that in the second embodiment. In this case, the Δaf detector **100***a* and so on in the ASC circuit **74***a* performs the processing using the sound effect frequency fasc, instead of the engine rotational frequency fe.

C2. A Variety of Control

C2-1. Selection of Driving Source

In the third embodiment, the driving ECU **170** selects the driving source on the basis of, for example, the accelerator opening degree θap. For example, if the accelerator opening degree θap is lower than or equal to a threshold value THθap**1** (hereinafter also referred to as a "low-load determination threshold value THθap**1**" or a "first opening degree threshold value THθap**1**") used for determining a low load state, the driving ECU **170** selects only the motor **12** as the driving source.

If the accelerator opening degree θap is lower than or equal to a threshold value THθap**2** (hereinafter also referred to as a "middle-load determination threshold value THθap**2**" or a "second opening degree threshold value THθap**2**") which is higher than the first opening degree threshold value THθap**1** and which is used for determining a middle load state, the driving ECU **170** selects only the engine **150** as the driving source. In this case, power generation in the motor **12** may be performed using the driving force of the engine **150**. If the accelerator opening degree θap is higher than the threshold value THθap**2**, the driving ECU **170** selects the motor **12** and the engine **150** as the driving sources.

The threshold values THθap**1** and THθap**2** may be varied in accordance with the vehicle speed V. The driving ECU **170** may select the driving source using an index (for example, the vehicle speed V) other than the accelerator opening degree θap.

C2-2. Selection Between ANC Process and ASC Process

In the third embodiment, selection between the ANC process (the ANC apparatus **80***a*) and the ASC process (the ASC apparatus **82***b*) is performed, for example, in the following manner. Specifically, a selector switch (not illustrated) used for switching between the ANC process and the ASC process is provided. The acoustic control ECU **40***b* performs the switching between the ANC process and the ASC process in accordance with the selection state of the selector switch.

Alternatively, the driving ECU **170** may perform the switching between the ANC process and the ASC process in accordance with an acceleration-deceleration state of the vehicle **10**B. Specifically, the driving ECU **170** may select the ASC process when the vehicle **10**B is in an acceleration state and may select the ANC process when the vehicle **10**B is in a constant-speed running state or in a deceleration state. The acceleration-deceleration state of the vehicle **10**B may be determined, for example, on the basis of a time differential value of the vehicle speed V. Alternatively, the acceleration-deceleration state of the vehicle **10**B may be determined on the basis of the accelerator opening degree θap itself or a time differential value or a second order differential value of the accelerator opening degree θap. When a value concerning the accelerator opening degree θap is used, the switching between the ANC process and the ASC process may be performed on the basis of the intent of the driver **302** for the acceleration-deceleration.

C2-3. Processing by Arbitrator **180**

As described above, the arbitrator **180** generates the sound effect frequency fasc on the basis of the virtual frequency fev from the fev setter **70** and the engine rotational frequency fe from the fe detector **160** and supplies the sound effect frequency fasc to the ASC circuit **74***b*. For example, the arbitrator **180** calculates the average of the virtual frequency fev and the engine rotational frequency fe and uses the average as the sound effect frequency fasc.

Alternatively, the arbitrator **180** may identify the driving state of the vehicle **10**B on the basis of the driving state signal Sd from the driving ECU **170** (selection of the driving source) and may perform the processing corresponding to the driving state.

Specifically, the arbitrator **180** outputs the virtual engine rotational frequency fev as the sound effect frequency fasc when only the motor **12** is selected as the driving source of the vehicle **10**B. The arbitrator **180** outputs the engine rotational frequency fe as the sound effect frequency fasc when only the engine **150** is selected as the driving source of the vehicle **10**B.

When both the motor **12** and the engine **150** are selected as the driving sources of the vehicle **10**B, the arbitrator **180** performs weighting to the virtual frequency fev and the engine rotational frequency fe to calculate the sound effect frequency fasc. In the weighting here, the ratio between a target torque of the motor **12** and a target torque of the engine **150** may be used as the ratio between the virtual frequency fev and the engine rotational frequency fe. The target torque may be acquired from, for example, the driving ECU **170**.

C3. Advantages in Third Embodiment

The ASC apparatus **82***b* according to the third embodiment has the following advantages, in addition to or instead of the advantages in the first embodiment or the second embodiment.

According to the third embodiment, it is possible to appropriately output the sound effect even if the operation state of the driving sources (the motor **12** and the engine **150**) is varied in the vehicle **10**B, which is a hybrid vehicle.

D. Modifications

While the embodiments of the present disclosure have been described above, it will be recognized and understood that various modifications can be made in the present disclosure on the basis of the content of description in this specification. For example, the following configurations may be adopted.

D1. Movable Object

Although the vehicles **10**, **10**A, and **10**B are exemplified as the targets to which the ASC apparatuses **82**, **82***a*, and **82***b* are applied in the above embodiments, the targets to which the ASC apparatuses **82**, **82***a*, and **82***b* are applied are not limited to the above ones, for example, from the viewpoint of the generation of the sound effect corresponding to the operation of the driving source or the vibration source. For example, the present disclosure may be applied to a movable object, such as a helicopter, an airplane, or a pleasure boat.

D2. Virtual Engine Rotational Frequency Setter **70**

The frequency, which is the fundamental frequency, is set in advance in accordance with the vehicle speed V in the fev setter **70** in the first embodiment and the third embodiment. However, how to set the frequency is not limited to the above one, for example, from the viewpoint of the calculation of the virtual frequency fev on the basis of the vehicle speed V and only one fundamental frequency may be used.

D3. Number of Reference Signals and Components

Although the three reference signals Sr**1**, Sr**2**, and Sr**3** are used in the above embodiments (refer to FIG. **2** and FIG. **4**), the number of the reference signals may be arbitrarily set depending on the specifications of the ASC apparatus. The numbers of the other components (the harmonic multipliers, the reference signal generators, and so on) are varied with the number of the required reference signals.

Although the numbers of the components including the harmonic multipliers **84***a*, **84***b*, and **84***c* and the reference signal generators **86***a*, **86***b*, and **86***c* are set to three, which is equal to the number of the reference signals Sr**1**, Sr**2**, and Sr**3** (FIG. **1**), in the above embodiments, the numbers of the components may be set to one or two for the processing.

D4. Total-Sound-Volume Correctors **102** and **102***a*

The total-sound-volume corrector **102** in the first embodiment and the third embodiment includes the first gain setter **110**, the second gain setter **112**, and the third gain setter **114** for the calculation of the common correction gain Gcom (refer to FIG. **2** and FIG. **8**). However, any of the gain setters may not be provided, for example, from the viewpoint of the calculation of the common correction gain Gcom.

Similarly, the total-sound-volume corrector **102***a* in the second embodiment and the third embodiment includes the first gain setter **110***a*, the second gain setter **112***a*, the third gain setter **114**, and the fourth gain setter **162** for the calculation of the common correction gain Gcom (refer to FIG. **4** and FIG. **8**). However, any of the gain setters may not be provided, for example, from the viewpoint of the calculation of the common correction gain Gcom.

The third gain setter **114** in the above embodiments uses the accelerator opening degree θap as a value indicating the load of the driving source (the motor **12** and/or the engine **150**) (FIG. **2**, FIG. **4**, and FIG. **8**). However, the value indicating the load of the driving source (the motor **12** and/or the engine **150**) is not limited to the accelerator opening degree θap as long as the value indicates the load of the driving source. For example, the vehicles **10** and **10**B including the motor **12** may use the torque of the motor **12** or input current into the motor **12** as the load of the driving source (the motor **12**). The vehicles **10**A and **10**B including the engine **150** may use a throttle position, the torque of the engine **150**, or a negative pressure in an intake manifold as the load of the driving source (the engine **150**).

The amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3** (the amplitude of the control signal Sc**1**) are adjusted using the common correction gain Gcom in the above embodiments. However, for example, the common correction gain Gcom is not limitedly used from the viewpoint of the adjustment of the amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3**. For example, the amplitudes of the reference signals Sr**1**, Sr**2**, and Sr**3** may be separately adjusted. Although a specific form of embodiment has been described above and illustrated in the accompanying drawings in order to be more clearly understood, the above description is made by way of example and not as limiting the scope of the invention defined by the accompanying claims. The scope of the invention is to be determined by the accompanying claims. Various modifications apparent to one of ordinary skill in the art could be made without departing from the scope of the invention. The accompanying claims cover such modifications.

We claim:

1. An active sound effect generating apparatus comprising:

a waveform data table that stores a waveform data corresponding to one waveform period;

a vehicle speed detecting unit that detects a vehicle speed;

a frequency setting unit that sets a vehicle-speed-corresponding frequency, which is a frequency defined on the basis of the vehicle speed detected by the vehicle speed detecting unit;

a reference signal generating unit that generates a reference signal having a harmonic in accordance with the vehicle-speed-corresponding frequency by sequentially reading the waveform data from the waveform data table;

a control signal generating unit that generates a control signal used for generation of a sound effect on the basis of the reference signal;

an output unit that outputs the control signal as the sound effect;

an amount-of-change-in-frequency calculating unit that calculates an amount of change in frequency, which is a time differential value of the vehicle-speed-corresponding frequency; and

a driving source load detecting unit that detects a load of a driving source of a vehicle,

wherein the control signal generating unit adjusts an amplitude of the control signal by varying an amplitude of the reference signal in accordance with the amount of change in frequency and the load of the driving source.

2. The active sound effect generating apparatus according to claim **1**,

wherein a frequency, which is a fundamental frequency, is set in advance in accordance with the vehicle speed in the frequency setting unit.

3. The active sound effect generating apparatus according to claim **1**,

wherein the vehicle is a hybrid vehicle including an engine and a motor as the driving source,

wherein the active sound effect generating apparatus further includes

a rotational frequency detecting unit that detects a rotational frequency of the engine; and

an amount-of-change-in-rotational frequency calculating unit that calculates an amount of change in the rotational frequency of the engine, which is a time differential value of the rotational frequency,

wherein the driving source load detecting unit detects a load of the engine,

wherein the reference signal generating unit generates the reference signal on the basis of the rotational frequency of the engine when only the engine is in a driving state, and

wherein the reference signal generating unit generates the reference signal on the basis of an arbitration frequency resulting from arbitration or selection of the vehicle-speed-corresponding frequency and the rotational frequency of the engine when both the engine and the motor are in the driving state.

4. The active sound effect generating apparatus according to claim **3**, wherein the reference signal generating unit generates the reference signal only using the rotational frequency of the engine when only the engine is in the driving state.

5. The active sound effect generating apparatus according to claim **3**, wherein the reference signal generating unit calculates the arbitration frequency by performing weighting to the vehicle-speed-corresponding frequency and the rotational frequency of the engine.

6. The active sound effect generating apparatus according to claim **1**, further comprising a memory device storing the waveform data table.

7. The active sound effect generating apparatus according to claim **1**, wherein the waveform data table comprises instantaneous value data stored as the waveform data, the instantaneous value data representing a predetermined number (N) of instantaneous values into which the waveform of a sine wave in one cyclic period is divided at equal intervals along a time axis.

8. The active sound effect generating apparatus according to claim **1**, wherein the frequency setting unit sets the vehicle-speed-corresponding frequency as a virtual engine rotational frequency corresponding to the vehicle speed detected by the vehicle speed detecting unit.

9. A vehicle comprising the active sound effect according apparatus according to claim **1**.

10. An active sound effect generating apparatus comprising:

a waveform data table that stores a waveform data corresponding to one waveform period;

a rotational frequency detecting unit that detects a rotational frequency of an engine;

a reference signal generating unit that generates a reference signal having a harmonic in accordance with the rotational frequency by sequentially reading the waveform data from the waveform data table;

a control signal generating unit that generates a control signal used for generation of a sound effect on the basis of the reference signal;

an output unit that outputs the control signal as the sound effect;

an amount-of-change-in-rotational-frequency calculating unit that calculates an amount of change in the rotational frequency of the engine, which is a time differential value of the rotational frequency;

an engine load detecting unit that detects a load of the engine; and

a vehicle speed detecting unit that detects a vehicle speed,

wherein the control signal generating unit adjusts an amplitude of the control signal by varying an amplitude of the reference signal in accordance with the amount of change in rotational frequency, the load of the engine, and the vehicle speed such that the amplitude of the control signal is set so as to be decreased with the decreasing vehicle speed detected by the vehicle speed detecting unit.

11. The active sound effect generating apparatus according to claim **10**, wherein the control signal generating unit decreases the amplitude of the control signal with the decreasing vehicle speed even though the rotational frequency of the engine increases.

12. An active sound effect generating apparatus comprising:

a memory device storing a waveform data table that stores a waveform data corresponding to one waveform period;

a vehicle speed detector that detects a vehicle speed;

a frequency setting circuitry that sets a vehicle-speed-corresponding frequency, which is a frequency corresponding to the vehicle speed detected by the vehicle speed detector;

a reference signal generating circuitry that generates a reference signal having a harmonic in accordance with the vehicle-speed-corresponding frequency by sequentially reading the waveform data from the waveform data table;

a control signal generating circuitry that generates a control signal used for generation of a sound effect using the reference signal;

an output circuitry that outputs the control signal as the sound effect;

an amount-of-change-in-frequency calculating circuitry that calculates an amount of change in frequency, which is a time differential value of the vehicle-speed-corresponding frequency; and

a driving source load detector that detects a load of a driving source of a vehicle,

wherein the control signal generating circuitry adjusts an amplitude of the control signal by varying an amplitude of the reference signal in accordance with the amount of change in frequency and the load of the driving source.

13. The active sound effect generating apparatus according to claim **12**,

wherein a frequency, which is a fundamental frequency, is set in advance in accordance with the vehicle speed in the frequency setting circuitry.

14. The active sound effect generating apparatus according to claim **12**,

wherein the vehicle is a hybrid vehicle including an engine and a motor as the driving source,

wherein the active sound effect generating apparatus further includes

a rotational frequency detector that detects a rotational frequency of the engine; and

an amount-of-change-in-rotational frequency calculating circuitry that calculates an amount of change in the rotational frequency of the engine, which is a time differential value of the rotational frequency,

wherein the driving source load detector detects a load of the engine,

wherein the reference signal generating circuitry generates the reference signal on the basis of the rotational frequency of the engine when only the engine is in a driving state, and

wherein the reference signal generating circuitry generates the reference signal on the basis of an arbitration frequency resulting from arbitration or selection of the vehicle-speed-corresponding frequency and the rotational frequency of the engine when both the engine and the motor are in the driving state.

15. The active sound effect generating apparatus according to claim **14**, wherein the reference signal generating circuitry generates the reference signal only using the rotational frequency of the engine when only the engine is in the driving state.

16. The active sound effect generating apparatus according to claim **14**, wherein the reference signal generating circuitry calculates the arbitration frequency by performing weighting to the vehicle-speed-corresponding frequency and the rotational frequency of the engine.

17. The active sound effect generating apparatus according to claim **12**, wherein the waveform data table comprises instantaneous value data stored as the waveform data, the instantaneous value data representing a predetermined number (N) of instantaneous values into which the waveform of a sine wave in one cyclic period is divided at equal intervals along a time axis.

18. The active sound effect generating apparatus according to claim **12**, wherein the frequency setting circuitry sets the vehicle-speed-corresponding frequency as a virtual engine rotational frequency corresponding to the vehicle speed detected by the vehicle speed detector.

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